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Towards a Practical Approach for TE Education: A Pilot Study at the University of Bath

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Abstract. Recent decades have seen increased interest in transdisciplinary (TD) research. To deliver on the promise of TD working there has been a call for the expansion of TD education in emerging literature. The challenge with proposed approaches is that they are often difficult to implement requiring significantly changed courses structures, and the coordination of teams of academic and industry experts to deliver. This creates a barrier to the main-streaming of TD education. Our research aims to create a practical approach for Transdisciplinary Engineering (TE) education which can be easily incorporated within existing course designs and in doing so facilitate wider disseminated. This paper presents the design and pilot of a TE session with MRes students from the University of Bath's, Centre of Doctoral Training in Advanced Automotive Propulsion Systems. The session is evaluated by way of student feedback. The results show broad satisfaction with the session. Six of the eight indicated that they were satisfied with the quality of the session (two students were neutral). All students considered that the course material was presented in a clear and understandable way. All students considered that the course was accessible to their level of understanding. Future work will see the session delivered within additional engineering MSc courses at Bath and internationally with informal agreements in place with Universities in Colombia, Korea and Poland.

Keywords. Transdisciplinary Education, Transdisciplinary Engineering Education, Engineering Education, Transdisciplinary Research, Transdisciplinary Engineering Research, Transdisciplinary Engineering, Transdisciplinary Engineering Design

Introduction

Smart factories and industry 4.0 result in complex systems where jobs tasks are augmented by both humans and automation [1]. Transdisciplinary (TD) approaches advocate purposive research which aims to address complex, real world challenges by the collaboration and integration of knowledge which goes above and beyond the academic disciplines [2-4]. As such, there is an expectation that engineering will be a designated field for TD research.

To deliver TD, there has been a call for the expansion of TD education [2, 5-9], and there is an emerging literature presenting potential approaches such as new TD courses and project based learning (PBL) activities. The challenge with these approaches is that

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they are often difficult to implement, requiring considerable effort to plan and execute [10-12]. This acts as a barrier to the main-streaming of TD education.

Within this paper a transdisciplinary engineering (TE) education session which can be delivered by one member of the engineering faculty, within a two hour period is described. The case study presents a pilot of the session with MRes students from the University of Bath's, Centre of Doctoral Training in Advanced Automotive Propulsion Systems.

The paper is structured as follows: First, a brief background to TD and the TD education literature (1). Following, the proposed TE session design is described (2). The pilot study with the Advanced Automotive Propulsion Systems (AAPS), Centre for Doctoral Training (CDT) is introduced (3) and student evaluation of the session presented (4). Finally, conclusions are formulated (5) and future work identified (6).

1. Transdisciplinarity

The origins of TD can be traced back to an educational conference held in Paris in 1970s [13]. Within this conference Jantsch presented a paper which described a hierarchical education/innovation system [2]. This conceptualised TD as a purposive system aimed at achieving societal meaning and value. In the conceptualisation the system is divided into four levels. The highest level is the Purposive level: societal meaning and value. Below this are the Normative (social-systems), Pragmatic (applied sciences), and Empirical (natural sciences) levels. To achieve TD all four levels of the system must be engaged, with coordination coming from the purposive level down.

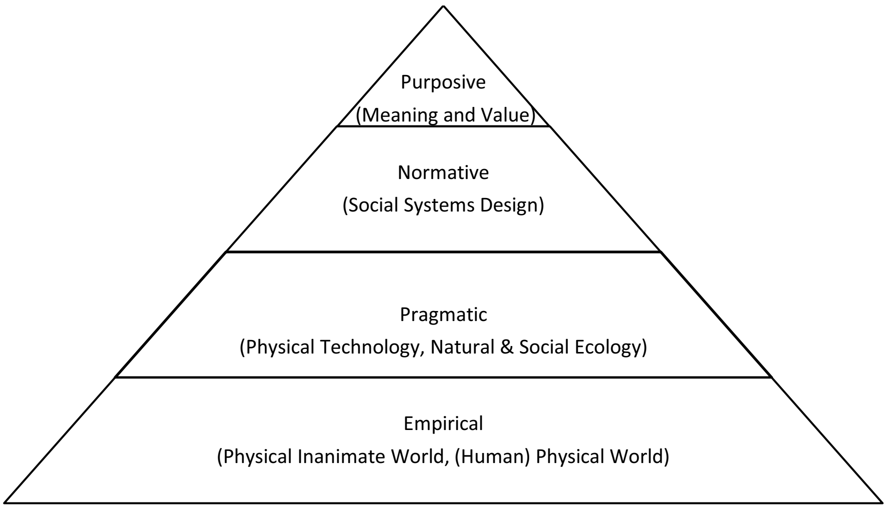

Figure 1. Adapted version of Jantsch's education/innovation system, viewed as a multi-level multi-goal, hierarchical system [14].

Despite these early endeavours, TD remained practically uncited until the 1990s and the rise in environmental awareness [13, 15]. In response to a requirement for new systems of working to address this complex problem TD re-emerges, albeit using a plurality of definitions, and papers referencing TD increase from seven in 1990 to in excess of 500 by 2018.

Within this growing body of work there has been a call for TD education, both generally and within engineering specifically [2, 5-9]. To deliver TD education the original work of Jantsch [2] calls for the restructuring of universities. Aligning with the hierarchical system presented in Figure 1, the institution would be reorganised into three types of units: system design laboratories, function orientated departments, and discipline orientated departments. These units create interdisciplinary coordination of the purposive/normative, normative/pragmatic, and pragmatic/empirical levels of the education/innovation system (Figure 2). As the students progress through their education (i.e. undergraduate, Masters, PhD) they advance up through the units.

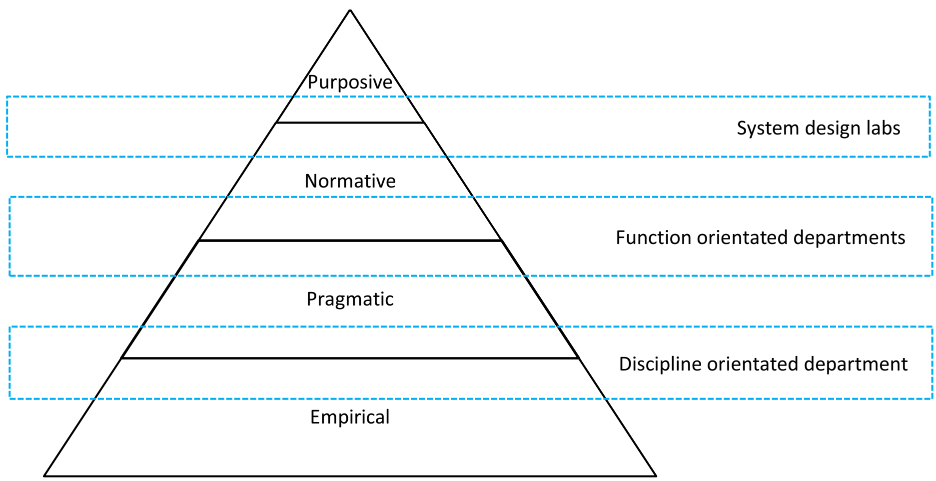

Figure 2. Transdisciplinary university structure. Adapted from Jantsch [2].

The education system proposed by Jantsch requires a significant shift from the traditional UK university set-up. Students would increasingly move towards self-education causing the "university professor, characteristic of the university today, to virtually disappear" [2]. To date, there is a lack of evidence to support that any University has implemented this approach. Rather, the tendency has been less revolutionary with TD education incorporated into existing university structures either through new courses e.g. Ertas [10], the addition of new modules to existing course content e.g. Kellam, Walther [11], or by stand-alone project based learning (PBL) challenges [16].

For Universities, deciding on which strategy to take and then designing new TD content is only one of the challenges faced. By its nature, the content of any TD education programme will be broad. To deliver this content will necessitate the engagement of staff from across multiple faculties and increased involvement from practitioners. This challenge is highlighted by Ertas [10] who called upon industry experts and academics from universities around the world to deliver a TD Master's course offer by Texas Tech University. This calls for lecturers who are open and able to work in a team comprising of academic, practitioner and client experts [17].

Our research aims to overcome these challenges by creating the structure for a practical approach for Transdisciplinary Engineering (TE) education. Within this paper we present a pilot of this session with MRes students from the University of Bath's, Centre of Doctoral Training in Advanced Automotive Propulsion Systems.

2. TE Session Design

A two hour session was constructed to be delivered in four sections (develop motivation; remember/understand; apply; analyse/evaluate), by one member of the engineering faculty (Figure 3).

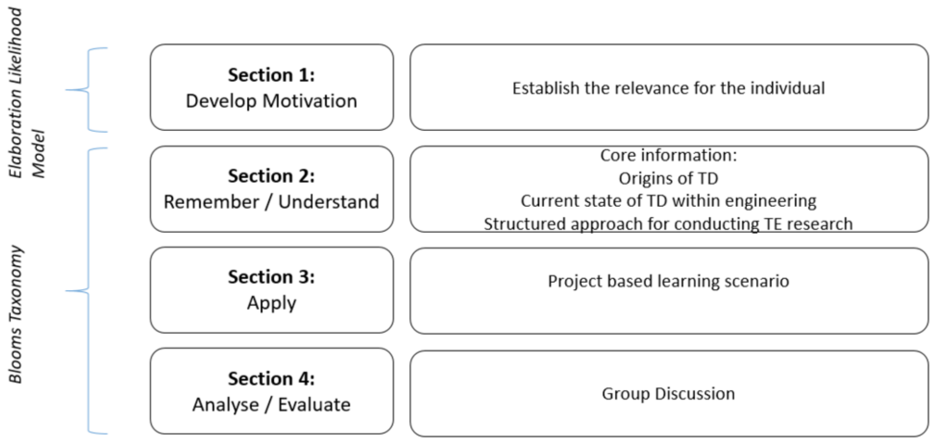

Figure 3. Transdisciplinary Engineering session structure.

The structure of the session was informed by two theories: The Elaboration Likelihood Model [18, 19] and Blooms Taxonomy [20]. The Elaboration Likelihood Model asserts that when a recipient is subjected to information which is intended to persuade them, they will adopt one of two strategies either following a central, or peripheral route. The central route is followed when the recipient engages and scrutinises the information they are presented with. The decision they reach (either supporting or opposing) is based on the strength of that information. However, if the recipient is unmotivated, or cognitively unable to process the information, their decision making will follow the peripheral route. In this case their decision will depend more on exterior cues such as the credibility of the source of the message.

Linked to The Elaboration Likelihood Model *Section 1* aims to "motivate" the students to engage with the information by detailing how the session is relevant to them i.e. how it links to course learning outcomes, or how the learning will be measured within summative assessments.

Bloom's Taxonomy is commonly used as a means through which to provide a shared language when designing educational courses [21, 22]. Aligning to Blooms Taxonomy**,** *Sections 2 – 4* progress the students through increasing higher levels of learning.

Section 2 is focused on remembering and understanding. Wognum et al. [23] identify not all project based learning will result in an acceptable solution and there should be an emphasis on the learning of shared processes and methodologies. Within this section a presentation is given which provides the students with core information: the origins of TD, the current state of TD within engineering [14], and a structured approach for conducting TE research [24]. Providing a "core" of information reflects the approach used by Ertas [10] in the design of his engineering Masters course.

Section 3 provides the students with the opportunity for application via Project Based Learning (PBL), a commonly used approach when teaching TD [23]. Although there are many advantages to this approach, in practice it is often challenging, taking considerable effort to plan and implement [23]. Our research aimed to create a practical approach for teaching TE. Therefore, the PBL approach was truncated with students asked to design the approach to be used within a project, but not to conduct the project.

A key challenge is selecting an appropriate project [23]. The project chosen here was based on a recent call by the UKRI Engineering and Physical Sciences Research Council (EPSRC). The call had an overall goal of supporting manufacturing research which contributes towards future growth in the UK economy. One of the three themes for which projects could be submitted was Zero Loss Systems (ZLS). The call stated that it was "supporting interdisciplinary research teams to push collaboration and fusion of the research approaches towards a transdisciplinary approach" [25]. Therefore, it provided a "real-world" scenario which had the potential to be addressed in a TE manner.

Although PBL initiatives are often undertaken in groups, we wished to remove the possibility that an individual may dominate the group. To capture the detail of the project a form was created. Based on the work of Jantsch [2] it aimed to elicit information which could be used to classify the level of disciplinarity of the project design. The three questions are:

1. When researching ZLS, what is the overarching *purpose* of your research?
2. When researching ZLS, which disciplines would you include in your team?
3. Other than the disciplines you identify in question 2, would you look to involve anyone else in the project? If so, who?

The students were then asked to classify the disciplinarity of their project using a decision tree. This decision tree, operationalises the work of Jantsch [2], and provides a simple yet robust method for identifying TD research.

Within *Section 4,* the students are guided through a group discussion in which they are encouraged to analyse/evaluate TE. The specific areas they were asked to reflect on are:

1. The level of disciplinarity of the research projects designed within Section 3.
2. The three questions from the project design form used within Section 3.
3. When a TE approach would be useful / not useful?
4. The enablers / barriers to TE?

3. Pilot Study: The Advanced Automotive Propulsion Systems (AAPS) Centre for Doctoral Training

Funded by the UK'S Engineering and Physical Sciences Research Council (EPSRC), The Advanced Automotive Propulsion Systems (AAPS), Centre for Doctoral Training [26] aims to educate the next generation of leaders in the automotive sector. Over the five years from 2019 it will support 86 PhD research projects. These projects are TE in nature; they will be conducted in collaboration with industry partners and look to address the challenges of the automotive sector in its transition towards a more sustainable future. The TE session was developed in response to a requirement of the Centre directors, and was piloted with their student cohort in November 2019.

The AAPS cohort follow a 1 + 3 year course structure. During the first (MRes) year students develop core personal, technical and research skills. The following three years focus on progressing their PhD research projects. The TE session was delivered as part of the MRes unit entitled "Propulsion System Evaluation". This semester long unit sees the students work in groups to firstly analyse the performance of a current propulsion system, and then to identify opportunities for innovation. The defined aims of the unit are:

1. Introduce students to a real automotive propulsion system through practical, data driven analysis of its performance and context
2. Work in a transdisciplinary team to harness the skills and knowledge brought by each individual.
3. Apply structured innovation processes to identify opportunities for future propulsion systems.

Eight of the cohort of nine students took part in the session which lasted two hours. Sections 1-3 were undertaken within the first hour, with the group discussion taking place in the second. Section 4 presents the evaluation of the pilot study.

4. Evaluation – Student Feedback

Evaluation of the session was conducted by way of student feedback. It aimed to capture the student satisfaction with the course rather than assess its performance against learning objectives. The reason for using student feedback as the means of evaluation was two-fold: 1. The University of Bath aspires to deliver excellent education. Within the UK, student satisfaction is a key indicator for University rankings. 2. At the time of conducting the pilot, the data through which to assess performance against learning objectives were not available. Within this unit "Transdisciplinary considerations" are one of a number of unit learning outcomes which are assessed through coursework (a Technical Brief) which students submit later in the academic year.

4.1. Results

In obtaining feedback the students were invited to anonymously complete the standard University of Bath feedback form. The form encompassed four areas: What they felt about the session (Table 1); the session's requirements for background understanding; what worked well; what could be improved; and any additional comments.

Table 1. Summary of TE session student feedback.

How do you feel about this statement?	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I can see how this session contributes to the overall programme of study	-	1	2	4	1
The learning outcomes for the session were clear throughout	-	2	2	2	2
The material in the course was presented in a clear and understandable way	-	-	-	3	5
The session was accessible for my level of understanding	-	-	-	1	7
Overall, I am satisfied with the quality of the session.	-	-	2	4	2

The student feedback (Table 1) demonstrates a broad satisfaction with the session. Six of the eight indicated that they were satisfied with the quality of the session (two students were neutral). All students considered that the course material was presented in a clear and understandable way. All students considered that the course was accessible to their level of understanding. Receiving a less positive response was how the session fitted within the overall programme and around the clarity of learning outcomes.

Although Section 1 (Develop Motivation), of the session aimed to inform the students of how the TE session met the learning outcomes of the unit, they appear to remain unclear on how the session fed into the overall programme with three of the eight giving a negative or neutral response. This is perhaps a consequence of the session being incorporated within a pre-existing course without the opportunity of amending the description of the course programme. Similarly, learning outcomes were set at a unit level prior to the decision to incorporate a TE session, as such they were high level and not directly aligned to the session content.

When asked to comment of the background knowledge required for the session, six of the eight considered it to be of the right level, whilst two considered it to be too little. In designing the session a conscious decision had been made not to require or assume any background knowledge of the subject. This decision was made for two main reasons: 1. The student's had not been allocated any free study time for research into TE. 2. TE is an emerging area and the seminal literature is yet to become apparent. This would make it difficult for students to navigate independently.

When asked to consider what worked well, the students identified the topic as "interesting" and helping towards "understanding and considering wider impacts on problems". The session was considered to have a " good balance of presenting and discussing". The presentation was considered to provide a "nice overall context" being of "a good length", and enabling them to learn "a lot in a small period of time".

Improvements include more time allocated to explaining the differences between the various disciplinarily levels: "delve into the specifics of TD, MD, ID and varying levels of this after the session", and "provide more scope for deeper discussion". The majority of the feedback related to the resources used in Section 3. These resources, which are based on the work of Jantsch, were considered by some to be confusing. Their comments included "Make question 1 more specific, too many ways to respond" and "Clarity between questions 2 & 3. Seems initially like the same question asked twice."

5. Conclusions

This research conducts a pilot study of a practical approach for TE education undertaken with MRes students from the University of Bath's, Centre of Doctoral Training in Advanced Automotive Propulsion Systems. Evaluation, conducted by way of student feedback, was broadly positive with all of the eight participants considering the course material to be clear and accessible, and seven of the eight considering that it was effective in helping them learn. Future iterations of the session will look to emphasise how the TE fits in to the overall programme of study and expand the time allocated to explaining the differences between disciplinarity levels.

6. Future Work

The development of the TE session, presented within this paper was the response to a need expressed by educational leaders. In meeting this requirement theoretical discussions around the benefits and drawbacks of a Transdisciplinary Engineering education were not considered. Going forward and in testing the generalisability of the approach questions of this nature must be addressed.

Plans have been made to deliver the session to ~80 University of Bath, Engineering Business Management and Business Innovation students and informal agreements are in place to run the session in Universities in Colombia, Korea and Poland. The scope of these future studies will be extended to incorporate these wider research questions. The results of the pilot and the subsequent studies will be synthesised and presented as a journal paper.

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References

[1] World Economic Forum, *The Future of Jobs Report 2018*. 2018.
[2] E. Jantsch, Inter- and transdisciplinary University: A Systems Approach to Education and Innovation, *Policy Sciences*, Vol 1, 1970, pp. 7-37.
[3] J.T. Klein, Discourses of transdisciplinarity: Looking back to the future, *Futures*, Vol. 63, 2014, pp. 68-74.
[4] C. Pohl, C and G.H. Hadorn, *Principles for Desigining Transdisciplinary Research*, Swiss Academies of Arts and Sciences, Bern, 2007.
[5] L. Bürgener and M. Barth, Sustainability competencies in teacher education: Making teacher education count in everyday school practice, *Journal of Cleaner Production*, Vol. 174, 2018, pp. 821-826.
[6] A. Ertas, T. Kollman and E. Gumus, Transdisciplinary educational performance evaluation through survey, *International Journal of Engineering Education*, Vol. 27, 2011, pp. 1094-1106.
[7] L. Jansen, The challenge of sustainable development, *Journal of Cleaner Production*, Vol. 11, 2003, pp. 231-245.

[8] C. Lyall, L. Meagher and A. Bruce, A rose by any other name? Transdisciplinarity in the context of UK research policy*, Futures*, Vol. 65, 2015, pp. 150-162.
[9] A.M. Madni, Transdisciplinarity: Reaching Beyond Disciplines to Find Connections*, 2007 Society for Design and Process Science*, Vol. 11, 2007, pp. 1-11.
[10] A. Ertas, Transformation of Higher Education: The Transdisciplainry Approach in Engineering*, IEEE Transaction son Education,* Vol. 46, 2003, pp. 289-295.
[11] N. Kellam, J. Walther, T. Costantino and B. Cramond, Integrating the Engineering Curriculum through the Synthesis and Design Studio, *Advances in Engineering Education,* Vol. 3, 2013.
[12] N. Wognum, C. Bil, F. Elgh, M. Peruzzini, J. Stjepandic and W.J.C. Verhagen, Transdisciplinary systems engineering: implications, challenges and research agenda, *International Journal of Agile Systems and Management*, Vol. 12, 2019, pp. 58-89.
[13] J.H. Bernstein, Transdisciplinarity: A Review of Its Origins, Development, and Current Issues, *Journal of Research Practice*, Vol. 11, 2015.
[14] S. Lattanzio, E. Carey, A. Hultin, R. Imani Asrai, M. McManus, N. Mogles, G. Parry and L.B. Newnes, Transdisciplinarity Within the Academic Engineering Literature*, International Journal of Agile Systems and Management*, 2020 (awaiting publication).
[15] F. Kessel and P.L. Rosenfield, Toward transdisciplinary research: Historical and contemporary perspectives, *American Journal of Preventive Medicine*, Vol. 35, 2008, pp. 225-234.
[16] University of Bath, 2019, *Take Part in the Grand Innovation Challenge,* Accessed: 10122019. [Online]. Available: https://www.bath.ac.uk/campaigns/take-part-in-the-grand-innovation-challenge-2019/.
[17] R.G. Klaassen, R.G, Interdisciplinary education: a case study, *European Journal of Engineering Education*, Vol. 43, 2018, pp. 842-860.
[18] R.E. Petty and J.T. Cacioppo, *Attitudes and persuasion: Classic and contemporary approaches,* W. C. Brown, Dubuque, IA, 1981.
[19] R.E. Petty and J.T. Cacioppo, *Communication and persuasion: Central and peripheral routes to attitude change*, Springer-Verlag, New York, 1986.
[20] B.S. Bloom, M.D. Englehart, E.J. Furst, W.H. Hill and D.R. Krathwohl, *Taxonomy of Educational Objectives, Handbook I: The Cognitive Domain*, David McKay Co Inc, New York, 1956.
[21] G. Fiegel, Incorporating learning outcomes into an introductory geotechnical engineering course, *European Journal of Engineering Education,* Vol. 38 2013, pp. 238-254.
[22] A. Thambyah, On the design of learning outcomes for the undergraduate engineer's final year project. *European Journal of Engineering Education,* Vol. 36, 2011, pp. 35-46.
[23] N. Wognum, C. Bil, F. Elgh, M. Peruzzini, J. Stjepandic and W. Verhagen, Transdisciplinary engineering research challenges, *Advances in Transdisciplinary Engineering*, Vol. 7, 2018, pp. 753-762.
[24] S. Lattanzio, L.B. Newnes, M. McManus, A. Hultin and D. Dunkley, Applying transdisciplinary engineering (TE) design research methodology to the challenge of managing decision support tool performance, *Advances in Transdisciplinary Engineering*, Vol. 10, 2019, pp. 261-268.
[25] UKRI, 2019, *Future Manufacturing Systems*, Accessed: 21102019. [Online]. Available: https://epsrc.ukri.org/funding/calls/future-manufacturing-systems/.
[26] The University of Bath, 2019, *EPSRC Centre for Doctoral Training in Advanced Automotive Propulsion Systems (AAPS)*. Accessed: 11122019. [Online]. Available: https://www.bath.ac.uk/centres-for-doctoral-training/epsrc-centre-for-doctoral-training-in-advanced-automotive-propulsion-systems-aaps/.